The Effects of Slow-Release Aluminum Sulfate on Bloom Color of *Hydrangea macrophylla*

by

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Abstract

Hydrangea macrophylla is a common greenhouse crop typically produced for the late winter and spring holidays. Most varieties are capable of producing either pink or blue flowers depending on aluminum content and pH of the growing medium. The goal of this experiment was to examine the effects of new controlled-release aluminum sulfate products on bloom color. This new product was applied as a topdress and a pre-plant incorporated mix using two different manufacturer recommended rates. Results were directly compared with those produced using a traditional water-soluble aluminum sulfate drench application. Controlled release aluminum sulfate was found to be at least as effective as traditional drenches while requiring only one application and significantly less labor than traditional drenches. Additionally, this new product was capable of producing blue flowers in the presence of phosphorus, which usually nullifies the effects of aluminum on flower color, leading to pink inflorescences. The results suggest controlled-release aluminum sulfate is a viable alternative to traditional aluminum sulfate drenches that can provide potentially superior results with a fraction of the labor costs.

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Introduction

Traditional production of potted hydrangeas with blue flowers involves the use of water-soluble aluminum sulfate to cause the blue pigmentation of flower sepals. This technique has proved very effective for over a century (Hydrangea Questions, 2005), but presents some problems related to high leachability in a greenhouse environment. Innovations in controlled-release technology already in use in the fertilizer industry are now being applied to the niche market of blue hydrangea production promising to nearly eliminate the problems with conventional aluminum sulfate applications. In this experiment, the effectiveness of the controlled-release aluminum sulfate product known by the trade name of Blue-Knight will be compared to that of traditional applications of water-soluble aluminum sulfate.

The goal of this experiment is to show the controlled-release product is capable of producing results equal to or better than the usual practice. If Blue-Knight shows good results, it has the potential to greatly reduce problems in blue hydrangea production by nearly eliminating the chance of over or under application of aluminum sulfate. Furthermore, this product can greatly reduce the labor required to produce blue hydrangea by eliminating the need for constant application of water soluble aluminum sulfate. In both cases, Blue-Knight promises to reduce the cost of production of blue hydrangeas and could be a product that growers must use to increase their profitability in an ever more competitive field.

Literature Review

Hydrangeas are a common garden plant across the United States and Europe popular for their large, showy flowers. Consequently they are grown commercially, mostly as potted plants, and sold from nurseries to supermarkets everywhere during the spring holidays. Due to their popularity, several species and countless varieties have been discovered and developed. Depending on who is asked, there are between 50 and 85 species of *Hydrangea,* but only five are widely cultivated. The most commonly grown species, *H. macrophylla,* is grown commercially for both cut flowers and potted plant production. Over 500 varieties of this one species have been documented (Dole, *et al*). *Hydrangea macrophylla* was "discovered" by European horticulturalists in the 18th Century in eastern China and a small part of northern Japan already in cultivation. Unfortunately it is unclear when or how it was discovered growing naturally (McClintock). Soon thereafter, the species was brought to the Royal Botanic Gardens at Kew in London, England in 1789.

Much of the Hydrangea's success as a garden plant stems from its ability to produce true-blue flowers. As one of a handful of plants than produce a true-blue, gardeners and horticulturalists have attempted to unlock the secrets to producing the most consistent and truest blue flowers for nearly three centuries. During this time period, however, a lot of misinformation has been published about the plant. Many who have gardened in their lifetime have heard of a technique using rusting nails to achieve a hydrangea with a blue flower, leading many to believe that iron is responsible for flower color. Nails would be driven into the soil or medium immediately adjacent to the plant in order to increase the iron concentration of the soil. Furthering the misbelief, the technique can actually aid in flower color change. As iron oxidizes, it releases hydrogen ions into the soil during its reaction to water, causing the pH of the soil to drop. The reduced pH in turn causes aluminum to break its bonds to various other elements and become soluble in the soil matrix thereby becoming available for plant uptake through the roots. In reality, it is a combination of a low pH and the presence of aluminum that causes Hydrangeas to produce blue blooms (Allen, R.C.). Because iron (or any other compound that releases hydrogen ions) can cause increased levels of plant-available aluminum in soils where aluminum is plentiful, hydrangea plants can be induced into producing blue flowers without the addition of supplemental aluminum.

Although the different hydrangea varieties can vary widely in areas like growth patterns, flower size and flower shape, flower color is determined almost entirely by one key soil condition: aluminum availability. *Hydrangea macrophylla* is among a few unique plants in that it acquires and accumulates aluminum, a non-essential nutrient. Nearly 75% of aluminum accumulating species belong to the Asteraceae and Rosaceae families with many other species spread amongst nearly ten other families, several of which are economically important. Interestingly, *Camellia sinensis*, one of the modern world's most significant crops over the last half millennium, has been shown to accumulate aluminum in high quantities in its leaf tissues (H. P. Carr *et al*). Among those aluminum accumulating species, the only species who's flower color depends on aluminum is *Hydrangea macrophylla.* (Hemsley 469, Jansen *et al*). Other *Hydrangea* species have white flowers and do not accumulate aluminum in high amounts.

Aluminum is the most abundant metal in the Earth's crust with a concentration of about 8% by weight (Miyasaka). Despite its sheer volume, aluminum is surprisingly unavailable to plants under most soil conditions as it's availability has a very strong relationship with pH. At pH values of 6.0 and below, aluminum forms water soluble compounds with sulfate, phosphate and oxygen, becoming increasingly available to plants in the form of the Al^{3+} ion as pH drops.

Starting at pH 5.0 (most naturally occurring soils are above pH 5.0) aluminum forms insoluble compounds, thereby becoming inaccessible to plants (Batten). In a commercial greenhouse operation that uses soilless, peat-based media only those materials which a grower adds will be present, therefore the element must be intentionally introduced and pH values closely monitored to ensure aluminum is available to the plant. The addition normally comes in the form of aluminum sulfate (Dole).

Although aluminum's purpose in Hydrangea production has been known for some time, aluminum's exact role in the formation of blue pigments has been somewhat of a mystery throughout the plant's history as a greenhouse crop. It is known that a single anthocyanin pigment, delphinidin 3-monoglucoside, is responsible for both pink and blue hues in the flowers. According to Yosida, *et al*, in the first half of the 20th century it was proven that aluminum is the key element responsible for the presence or lack of the blue form of the pigment delphinidin. However, in spite of several recent studies, the mechanism behind the different Hydrangea hues remains unclear. Paradoxically, while attempting to uncover the mechanism, it was found that the pH in the cellular vacuoles is much higher in blue-colored cells than in pink-colored cells. Considering that vacuole pH in red-colored cells is low while the environmental pH (media pH) is relatively high, this phenomenon is quite strange. To further complicate the matter, the cause behind the interesting pH readings has yet to be truly understood (Yoshida, *et al*).

With the knowledge of how to produce true blue tones, hydrangea growers have managed to nearly perfect their growing techniques. Current production of *Hydrangea macrophylla* uses water-soluble aluminum sulfate combined with a highly acidic growing media to produce plants with blue flowers (Dole). This technique has been very successful when performed correctly, but presents several pitfalls. Perhaps the biggest short coming of the technique is due to aluminum sulfate's high solubility in water. It can be easily leached from soil and media during irrigation leading to lower-than-desired aluminum levels (Tisdale, *et al*). To help avoid the technique's flaws, a new product has been developed by the X-Calibur fertilizer company under the name of Blue-Knight. Utilizing a slow-release mechanism similar to many popular slow-release fertilizers already on the market, X-Calibur has found a way to provide the aluminum necessary for Hydrangea production using only a single application of its product.

Blue-Knight falls into a category of fertilizers known as controlled-release fertilizers. These products include several methods by which a single application of a product results in a consistent dosage of nutrients over a pre-determined period of time. The rate and time span of nutrient release can be controlled in several ways ranging from a simple technique like larger pellet size (also known as prills) to more expensive sulfur-coated prills. Perhaps the most common and the latest slow-release technology to reach the market is polymer coating. Fertilizer prills are coated in a plastic that reacts to one or several environmental factors to induce the release of the product (Murphy). The best known controlled-release product is Osmocote manufactured by the Scotts fertilizer company. According to Scotts, Osmocote works on the principle of osmosis where water is able to penetrate the polymer, dissolving the product within, allowing it to escape out of the prill and into the soil or medium by diffusion. The company also claims the release of the product is affected only temperature, not moisture levels. Most slow-release fertilizers are available in nearly any formulation for use with most greenhouse and field crops.

Slow-release fertilizers have a distinct advantage over traditional fertilization. Particle size is quite large and nutrients are released at a predetermined rate, therefore it is very difficult for nutrients to move through and leach from the growing medium. With traditional fertilizers the product may easily move through the soil with water movement such as irrigation. With over-watering, many greenhouse crops can experience poor nutrition and nutrient deficiencies in spite of an appropriate nutrition program. On the other hand, in an effort to counteract the constant leaching of irrigation, growers may apply higher rates of fertilizers, thereby increasing the cost of production and risk of fertilizer damage. With a constant release rate and resistance to leaching, controlled-release fertilizers can help protect against poor nutrition and lower production costs, even with too much irrigation (Murphy).

There are disadvantages to controlled-release fertilizers as well. Most notably, they generally cost a great deal more than traditional fertilizers so they are reserved only for crops in which the cost is outweighed by the reduced risks of using other fertilizing methods like high-value crops. Since the plants sell for such high prices in stores, it may prove worthwhile to use a more expensive system if it means insuring the safety and quality of the crop. In addition to cost, controlled-release fertilizers do not store well once mixed with medium as their release rate is related to time. If not used quickly, medium with controlled-release fertilizers will cause very high levels to occur. Polymer coated fertilizers cannot be mixed with media prior to steam sterilization due to the extreme amounts of heat and moisture used in the process, as it would lead to a premature release of nutrients, high salt levels and wasted product. Therefore, slow-release fertilizers are either incorporated into media as close to planting time as possible or top dressed into individual pots after potting (Murphy).

Blue-Knight is a controlled-release form of aluminum sulfate released to growers in 2010. It is manufactured by X-Caliber LLC using a polymer coating originally licensed in Germany and was the first controlled-release form of aluminum sulfate widely available to commercial Hydrangea growers. According to the manufacturer, the polymer coating, called

Plantacote, is unaffected by media moisture, pH, composition or microorganisms. They also claim that its release is governed strictly by temperature and is proportionate to the growth level of the plant at any given temperature. According to its label, Plantacote takes 2-3 weeks to begin releasing nutrients once mixed into a media, and since its release is governed by temperature, it can be premixed after steaming several weeks prior to planting. While many of X-Caliber's fertilizer products are available in several formulations and release rates, Blue-Knight is only manufactured in one formulation and an 8-12 week release formulation, corresponding to normal Hydrangea forcing schedules (The Hydrangea Blues). While research on slow-release fertilizers has been very thorough, Blue-Knight is the first product of its kind on the market and research on the product's efficacy is very limited as a result.

A few years after the development of Blue-Knight, a nearly identical product has come onto the market. It is known as Florikote Sapphire and is manufactured by the Florikan fertilizer company. While Blue-Knight is no longer manufactured, Florikote Sapphire has taken its place with a similar 3-4 month release time and 15% aluminum sulfate content. Although it functions nearly identically to Blue-Knight according to the Florikote Sapphire label, its most important difference is that it is available to consumers, not just greenhouse growers! While this experiment is testing the effectiveness of Blue-Knight, Florikote Sapphire is a nearly identical substitute and should be treated as the same product for all intents and purposes. If the results of this experiment show that Blue-Knight indeed produces true blue tones, ordinary gardeners may be able to achieve the color with only a single application of one product.

Materials and Methods

The growing medium used consisted of 2 parts sphagnum peat moss, 1 part fir bark and 1 part perlite which was then steam sterilized. Media pH after steaming was approximately 4.1. Additionally, no dolomite or treble superphosphate was added to the medium. The cultivars tested were ‘Merritt’s Supreme,’ ‘Mathilda Gutges’ and ‘Berlin’ which were received as dormant, four-cane four-inch liners. They were transplanted into six-inch azalea pots and watered in with ordinary municipal water on January 24, 2014. *Osmocote plus* controlled-release fertilizer was applied on January 24 at the rate of 12 grams per pot with an analysis of 15-9-12. The *Osmocote* contained all micronutrients as well.

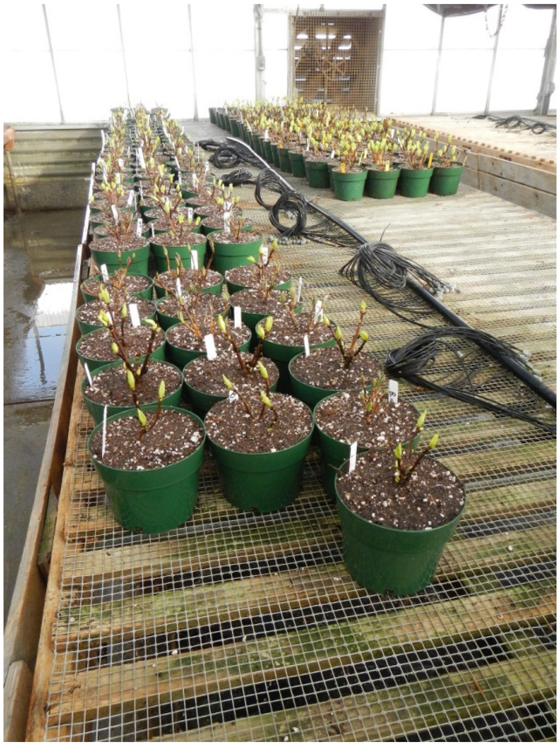

Figure 1: Liners just after potting showing slightly different levels of development

Plants were placed randomly into nine treatments containing three plants from each variety for a total of nine plants per treatment. All treatments were grown in a climate controlled greenhouse averaging 65°F night time temperature and 2500-4000 FC of light intensity. The control group received no $AlSO_4$ of any kind. Treatments one and two received X-Calibur Blue-Knight as a topdress in each pot at the manufacturer recommended rate of 15 grams per pot and 20 grams per pot respectively. Treatments three and four received X-Calibur Blue-Knight as a pre-plant incorporated mix at the manufacturer recommended rate of eight pounds (3.6 kg) per cubic yard and twelve pounds (5.4 kg) per cubic yard of medium respectively. Treatments five and six received traditional drench applications of water-soluble $AlSO_4$ once every two weeks at the rates of 28 grams per pot and 56 grams per pot respectively. Treatments seven and eight received drench applications of water-soluble $AlSO_4$ once per month at the rates of 56 grams per pot and 112 grams per pot respectively. See Table 1 for treatment details.

Table 1: Treatments and Application Method

	Tx 1	Tx 2	Tx 3	Tx 4	Tx 5	Tx 6	Tx 7	Tx 8	Control (Tx 9)
Rate of $AlSO_4$	15g/pot	10g/pot	3.6kg/yd^3	5.4kg/yd^3	28g/pot	56g/pot	56g/pot	112g/pot	0 grams
Application Method	Top dress	Top dress	Pre-plant Incorporated	Pre-plant Incorporated	Bimonthly drench	Bimonthly drench	Monthly drench	Monthly drench	None

The drench procedure consisted of using enough water to give each pot approximately eight ounces of $AlSO_4$ solution at the required concentration. One batch of solution was mixed with 252 grams of product for treatment five. One batch was mixed with 504 grams of product for treatment 6. One batch was mixed with 504 grams of product for treatment seven. One batch was mixed with 1008 grams of product for treatment eight. The solution was then applied by hand to each pot using a measuring cup. All plants were given sufficient water before the drench to achieve a saturated medium.

Electrical Conductivity and pH were measured using a combined hand-held pH and EC meter and a dilution ratio of 1:5 by weight of medium:water. Medium samples were taken from the center of randomly selected pots in each treatment. Samples contained as few roots as possible. Samples were collected as close to field capacity as possible.

Data was collected throughout the experiment. pH and Electrical Conductivity (EC) readings were taken roughly every 2 weeks to record soil chemistry. Photographs and observations were taken to record overall plant growth, health and bloom quality throughout the experiment. At the end of the experiment, data collected included flower color, inflorescence size and root growth/root quality.

To analyze the flowers for color quality, each plant's flowers were photographed under identical lighting conditions inside a white light tent using a Nikon AW100 camera. The photographs were then analyzed using Adobe Photoshop to obtain precise color readings of each flower. Each flower's pixels were blurred using a 40-pixel blur in order to achieve an average of all colors present in each flower (Kesumawati 2009). The averaged colors were then compared visually to a digital representation of the RHS color system. Data was analyzed to determine statistical significance. Data analysis performed consisted of mean, minimum, maximum and

range calculations for each data set. Microsoft Excel was used for all data calculations.

Figure 2: Example photo showing flower color data collection method.

Results and Discussion

Flower Color

The purest blue tones were produced using either the topdressed, controlled-release Blue-Knight (‘Mathilda Gutges’) or a traditional water-soluble drench of aluminum sulfate every two weeks (‘Merritt’s Supreme’ and ‘Berlin’). Drenching every four weeks produced the poorest blues second only to the control group. The control group, which received no supplemental aluminum sulfate, produced the purest pink flowers of all treatments by far. ‘Mathilda Gutges’, which produced the purest blue flowers of the experiment, produced flowers that rated about 70 on the RHS scale in the treatments group. Berlin was similarly affected with flower color in the control group estimated to be about 64 on the RHS scale.

Flower color was highly variable across the three cultivars. ‘Merritt’s Supreme’ had the purest pink bloom by far, measuring between 57 and 71 on the RHS Color Chart. These numbers denote colors very near to red despite any of the aluminum sulfate treatments. Flower color only seemed to be mildly affected by the different treatments and no real pattern seems to exist in the results of ‘Merritt’s Supreme’. The other two cultivars seemed to have much more profound reactions to the different treatments. ‘Mathilda Gutges’ showed the truest blues of the entire experiment at 92 on the RHS scale. The truest blues were achieved in treatment 1 using the low-dose, topdressed Blue-Knight and in treatment 5 using the low-dose, two-week AlSO4 drench. Both results are significantly truerer blue than the treatments using higher doses of aluminum sulfate.

Treatments receiving $AlSO_4$ as a drench ranged in flower color from RHScg 91 to 60. The highest value was achieved by ‘Mathilda Gutges’ in treatment 5 and the lowest value was achieved by ‘Merritt’s Supreme’ in treatment 5 and treatment 8. ‘Merritt’s Supreme’ and ‘Berlin’ also achieved their bluest flowers of the experiment in treatment 6 at RHScg 71 and treatment 5 at 87 respectively. Bimonthly drenches generally achieved higher RHScg values than those receiving monthly drenches. ‘Mathilda Gutges’ for example ranged in color from RHScg 91 to 88 while receiving bimonthly drenches and from 78 to 75 while receiving monthly drenches (Table 2).

Treatments receiving BK (Table 1) as a top dress ranged from RHS color group (RHScg) 92 to 60 with the truest blue occurring in treatment 1 in ‘Mathilda Gutges’ at RHScg 92. The other two cultivars showed almost no difference between treatments 1 and 2. Treatments receiving BK as a pre-plant incorporated application produced less blue flowers with RHScg values ranging from 85 in ‘Mathilda Gutges’ to 57 in Merritt’s Supreme. The lowest (pinkest) RHScg value occurring in ‘Merritt’s Supreme’ treatment 3 equaled the pinkest flowers of the experiment achieved in the control group. Flowers of the other two cultivars were measured to be within the same RHScg showing no difference in color between the two rates of incorporated BK (Table 2).

Table 2: Flower Color in RHS color guide units (RHScg).

Treatment #	Tx 1	Tx 2	Tx 3	Tx 4	Tx 5	Tx 6	Tx 7	Tx 8	Control
Merritt's Supreme	63	60	57	59	60	71	63	60	57
Berlin	78	81	74	74	87	82	78	82	64
Mathilda Gutges	92	85	85	85	91	88	78	75	70

Treatment 1 obtained true blue color for a simple reason: a higher rate of product used means there is more aluminum present in the media for the plant to uptake therefore creating the highest concentration of aluminum-complex anthocyanin and a truer blue flower color. Unfortunately, when looking at other treatments, higher levels of product used did not necessarily coordinate with truer blue flowers. To explain the truer blue color in treatment 5 which used a lower rate than treatment 6 is not so simple. It is possible that the added amount of AlSO4 (a salt) present in treatment 6 may have actually hampered flower development leading to smaller flowers (Table 3). Evidence can be found when EC values are looked at. EC was slightly higher in treatment 6 than treatment 5 over the final month of the experiment. Elevated salt levels can not only inhibit growth and flower development directly, they can also inhibit absorption of other substances from the growing medium such as aluminum (Alam 1999). Oddly, 'Merritt's Supreme's' truest blue flower was found in treatment 6 in spite of elevated salt levels. The variety across the whole experiment has shown flower colors with much more pink than expected. 'Merritt's Supreme' is known as a variety that produces both pink and blue flowered plants equally well so perhaps it requires a higher level of aluminum to achieve true blue flowers. It is more likely, however, that some sort of error occurred during production leading to less-than-ideal results with this variety.

As was expected, the control produced the truest pink flowers of the experiment. The control group received no supplemental aluminum. In general, plants destined for production of blue-flowered plants will receive applications of aluminum sulfate while still in 4 inch liners so there is some aluminum sulfate present prior to bud break. While all three varieties produced their truest pink flower colors, some plants contained hints of blue in their inflorescences. 'Mathilda Gutges' for example produced flowers that had more muddled pink/purple tones than any treatment of 'Merritt's Supreme', even without any supplemental aluminum. The slightly blue flowers of 'Mathilda Gutges' in the control treatment are a result of residual aluminum sulfate leftover from liner production.

Finally, the high amount of variability in flower color is most likely a result of problems during the experiment. For example, several plants never reached flower due to wilt damage.

Other plants, while not visibly damaged were most likely stunted due to stress and failed to develop properly leading to small, underdeveloped and poorly pigmented flowers.

Figure 3: Photo showing all plants at the end of experiment. Plants are arranged by treatment, then variety (L to R Berlin, Mathilda Gutges, Merritt's Supreme)

Inflorescence Size

Although flower head size was not being tested specifically in this experiment, it was still measured because it is a good indicator of overall plant health and vigor. Furthermore, plants with larger inflorescences are more desirable than those with small heads so head size is and important point of discussion.

The largest head size for all three cultivars was produced in treatment 5 which received a low dose of water-soluble aluminum sulfate every two weeks. Heads averaged approximately 10.7 centimeters (Berlin) to 12.8 centimeters (Merritt's Supreme). The smallest head sizes were not produced in any one treatment, but rather varied with cultivar. Generally, treatments using Blue-Knight produced larger heads on 'Mathilda Gutges' and 'Merritt's Supreme', but smaller inflorescences on 'Berlin.'

Flower head size showed more variability on plants receiving traditional $AlSO_4$ drenches than while receiving BK applications. Flower head size ranged from 7.8 cm to 12.8 cm. Both the largest and smallest inflorescences were achieved by plants receiving drench applications. Treatment 5 achieved the largest head size with all three cultivars of the experiment.

Table 3: Flower Head Size (cm)

Treatment #	Tx 1	Tx 2	Tx 3	Tx 4	Tx 5	Tx 6	Tx 7	Tx 8	Control
Merritt's Supreme	12.25	11.67	11.75	11.83	12.83	11.33	11.33	12.17	12.67
Berlin	8.33	9.33	8.50	8.33	10.67	9.67	9.67	7.75	10.00
Mathilda Gutges	11.75	11.67	12.00	10.33	12.67	10.50	10.50	11.33	9.17

Inflorescence size showed only slight variability between treatments receiving BK $AlSO_4$. On average, ‘Merritt’s Supreme’ ranged from 11.8 to 12.3 cm, ‘Berlin’ from 8.3 to 9.3 cm and ‘Mathilda Gutges’ from 10.3 to 12.0 cm. The largest inflorescence was achieved by ‘Merritt’s Supreme’ in treatment 1 while the smallest was achieved by ‘Berlin’ also in treatment 1 (Table 3). It is generally accepted that high salt levels in growing media will adversely affect plant growth. Elevated EC will generally stunt growth and inhibit rooting.

Growing Medium

pH was measured throughout the experiment to monitor acidity of the growing medium. The control group which did not receive any aluminum sulfate maintained the highest pH readings. At the end of the experiment, the Control group averaged pH 4.3, nearly one-half of a pH unit higher than the next nearest treatment which equates to roughly one fifth as acidic as the next nearest group. Additionally, after an initial drop in pH, the Control group was the only group to demonstrate a consistent rise in pH. Also, the pH of the irrigation water was tested to be pH 7.2.

Growing medium pH was extremely low during the experiment. The lowest pH readings came from treatment 4 which received the highest dose of incorporated Blue-Knight bottoming out at a pH of 2.9 on March 18th. The treatment's acidity would decrease significantly by the time of final data collection on April 10th, rising slightly for the final sampling. All treatments except for the control group seemed to fit a more-or-less downward trend of pH values as the experiment proceeded. Most treatments ended at or very near a pH of 3.5.

Table 4: Medium Acidity (pH)

Treatment #	Jan 29 '14	Feb 7 '14	Feb 21 '14	Mar 18 '14	Apr 10 '14
Control	4.1	3.9	3.7	4.2	4.3
1	4.1	3.9	3.1	3.2	3.5
2	4.1	3.9	3.6	3.0	3.3
3	3.8	3.2	3.3	3.1	3.5
4	4.0	3.2	3.0	2.9	3.5
5	4.1	3.8	3.9	3.7	4.0
6	4.1	3.8	3.5	3.5	3.7
7	4.1	3.8	3.6	3.9	3.8
8	4.1	3.8	3.5	4.0	3.9
Irrigation Water				7.2	

Medium pH was a constant issue during the experiment. The assumption was made before any medium was mixed that using sphagnum peat moss without the addition of dolomite lime would lead to a medium with an ideal pH of 4.5 to 5. Unfortunately, medium pH was much lower than expected in all treatments. Not only was the medium much more acidic than expected (table 4), the addition of aluminum sulfate served to lower the pH even further. Aluminum sulfate is widely known as a pH reducer and is even marketed in retail nurseries as an effective way to lower the pH for plants like blueberries, azaleas and, of course, hydrangeas. It comes as no surprise that treatments receiving high doses of aluminum sulfate developed extremely high acidity (table 4) with pH values recorded as low as 2.9. The effects of extreme pH values is widely documented with the primary effect being greatly reduced nutrient uptake leaded to stunted, underdeveloped plants.

Electrical Conductivity (EC) was also measured throughout the experiment to monitor soluble salts present in the growing medium. Unfortunately, EC is only an indirect measurement of accumulated salts in the medium so it is impossible to determine how much of the change in EC resulted from the fertilizer, aluminum sulfate or naturally-occurring minerals in the irrigation water. In Chart 2, it is clear that in every treatment the EC rose by the end of the experiment. Treatments using Blue-Knight as an incorporated product generated the highest maintained EC readings (treatments 3 and 4), while the highest dose bi-monthly treatment of standard water-soluble aluminum sulfate (treatment 8) generated the highest recorded EC of the experiment at 1.0 µS/cm. Interestingly Treatment 8 demonstrated the largest ranging EC readings between high and low points. Treatments receiving Blue-Knight as a topdress also maintained consistent EC readings, but stayed at a lower level than the other controlled-release treatments.

Table 5: Medium Electrical Conductivity (µS/cm)

Treatment #	Jan 29 '14	Feb 7 '14	Feb 21 '14	Mar 18 '14	Apr 10 '14
Control	0.2	0.2	0.4	0.3	0.53
1	0.2	0.2	0.7	0.3	0.57
2	0.2	0.2	0.5	0.5	0.50
3	0.3	0.7	0.8	0.4	0.47
4	0.2	0.6	0.8	0.6	0.80
5	0.2	0.2	0.7	0.1	0.53
6	0.2	0.2	0.5	0.2	1.10
7	0.2	0.3	0.5	0.5	0.67
8	0.2	0.2	1.0	0.1	0.57
	Irrigation Water			0.4	

Electrical Conductivity is always a concern in an experiment when fertilizer rates are being examined. Treatments 2, 4, 6 and 8 received relatively high rates of aluminum sulfate and so it was expected for these treatments to achieve high EC measurements. Treatments 6 and 8 received only drench applications so EC values naturally spiked immediately following treatments and slowly fell as irrigation water leached much of the product from the growing medium. Treatments 2 and 4 did not undergo the natural fluctuations of a traditional drench application since aluminum sulfate was delivered in a with a controlled release form. As was expected, EC values began quite low in treatments 1-4, rising to their highest readings around four weeks into production (Table 5).

Overall Plant Health

Upon receiving the plants as four-inch liners, many plants were already undergoing bud break even while in the shipping boxes when received. While all plants has some green showing on all terminal buds, which is normal, the cultivar ‘Merritt’s Supreme’ seemed to have come out of dormancy the earliest (Figure 4). Most ‘Merritt’s Supreme’ plants already had several

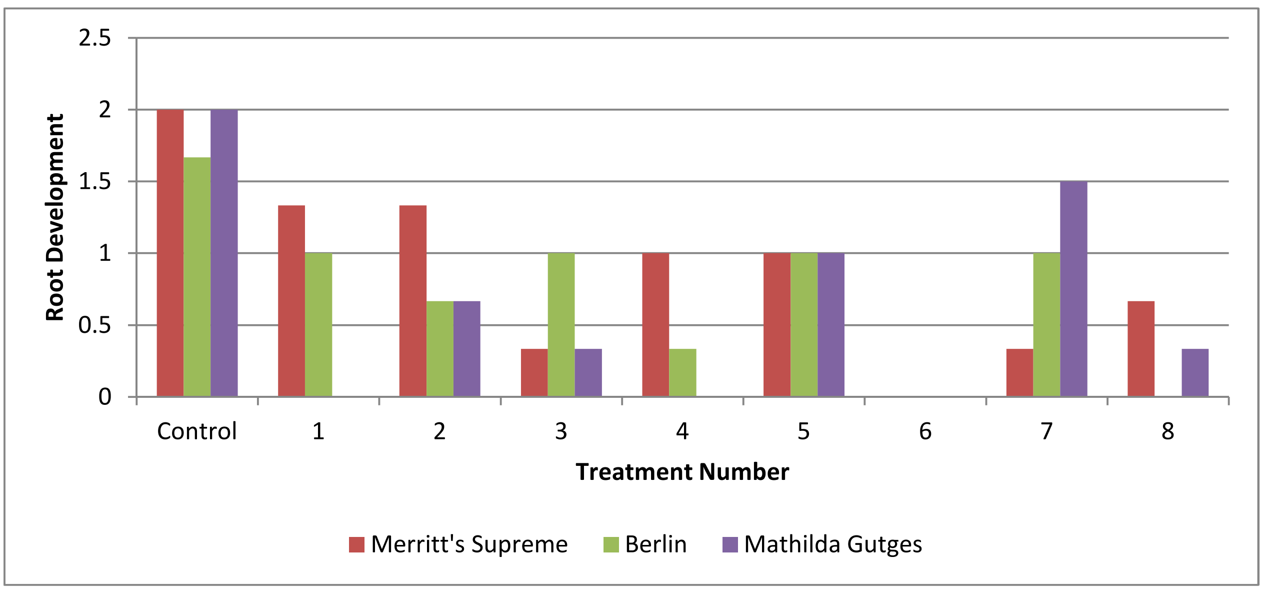

Figure 4: Root development across all treatments

significantly expanded leaves. This early development especially in the Merritt’s Supreme group carried over into the greenhouse as well. The ‘Merritt’s Supreme’ cultivar laid down more leaves faster than the other two cultivars and began showing flower buds at least two weeks before the next earliest cultivar, and up to a month earlier than the latest cultivar.

Plants were healthy throughout the experiment with no signs of disease or pests present. Three plants died during the experiment and two others failed to flower due to drought stress damage. While there were differences in dormancy, all plants grew consistently once dormancy was broken. During several hot spells, some wilt damage was recorded on leaf margins in spite of moist media and leaf syringing. The larger, more developed plants seemed to succumb to heat more easily than those that broke dormancy later.

'Merritt's Supreme' showed better rooting overall than the other two varieties tested because when the plants were received from the liner producer 'Merritt's Supreme' had already broken dormancy and appeared to be one to two weeks more developed than the 'Mathilda Gutges' and 'Berlin' plants. The 'Merritt's Supreme' plants were beginning to actively grow

Figure 5: Photo showing small flower buds showing. Note the larger, more developed inflorescences on the 'Merritt's Supreme' plants.

even before being planted in their 6 inch pots while the other varieties would take at least two weeks to begin to grow. And, since shoot growth is often a good indicator of root growth, it can be gleened by the vigorous top growth on all ‘Merritt’s Supreme’ plants that these plants were also rapidly growing roots as well. ‘Merritt’s Supreme’ was about two weeks earlier in overall development throughout the experiment (Figure 5).

Root growth in nearly every treatment was much poorer than expected. Nearly all treatments had one or two plants with no visible root growth beyond their original 4-inch liner pots with most plants showing only minimal root development leading the researcher to believe that most plants had poor medium-to-root contact thereby reducing the plants’ ability uptake fertilizer, water and aluminum sulfate. As a result we observed widespread heat and drought stress across most treatments. Additionally, and most importantly, we observed inconsistent coloring and inflorescences with poorly colored sepals. Nearly all problems that arose with the plants in this experiment can be directly or indirectly tied to problems in the root zone, including, but not limited to the less-than-ideal flower color.

Problems

Due to limited time and resources, this experiment could only be attempted one time in its entirety. As a result, several shortcomings in experiment design and execution only became apparent part-way through the experiment. What follows is a list of any observed problems that occurred during the experiment, how they may have affected results, and what, if anything could have been done to prevent them.

The largest oversight of this experiment occurred while it was being designed. It was not until nearly all plants had been harvested that the mistake was explained. One of the many objectives of this experiment was to devise a way to apply all fertilizer and aluminum sulfate in one application of product. This was accomplished by using controlled-release aluminum sulfate and commercially available *Osmocote* controlled release fertilizer. Much care was taken during preparation of the experiment to prevent the plants from being exposed to any form of phosphorus as this would lead the aluminum binding with the phosphorus rendering the aluminum unavailable to the plants. What became obvious while measuring the results was the phosphorus already added to the *Osmocote* by the manufacturer had interfered with aluminum absorption in the growing medium. It is unclear how such a lack of judgment was allowed to go unchecked for so long, but it ultimately skewed the results in a profound way. On the other hand, since all plants received roughly the same amount of fertilizer and therefore the same amount of phosphorus, it might be assumed that roughly the same amount of aluminum was bound in treatment leaving behind whatever excess aluminum was present. This explains why some treatments, particularly those receiving high rates of aluminum sulfate still managed to produce some true-blue inflorescences in spite of the presence of phosphorus. It would be expected that had the phosphorus not been present that the results would have been clearer. Perhaps those plants that produced blue flowers had actually received far too much aluminum sulfate. It is the researcher's belief that the high-rate treatments received much more aluminum sulfate than was needed to produce ideal results and would have demonstrated diminishing returns in the absence of phosphorus. Some of the low-rate treatments may have even produced inflorescences with extremely dark-blue sepals

Perhaps the most glaring problem throughout the experiment was the pH of the growing medium. As noted earlier, pH was much too low even for hydrangea production. This helped to inhibit nutrient absorption and root development. It is widely accepted that many plant essential nutrients such as potassium and sulfur become exceedingly unavailable to plants while iron can rise to toxic levels at the same time in extremely acidic environments (pH less than 5.0). So, while we achieved optimum aluminum availability due to the low pH, the benefits were outweighed by decreased root growth and poor nutrient absorption. Furthermore, while the lack of root growth seems to be cause of many of the physiological problems with the plants and their inflorescences, medium pH seems to be the cause of the poor root development and is therefore the cause of most plant-related problems. For example, the control group showed the best rooting of all treatments by far with almost all plants of all three varieties filling their respective pots with roots. This treatment had the highest measured pH throughout the experiment (Table 4). It should be noted that the control group received no aluminum sulfate, leading to the lowest EC levels of any treatment. The low salt levels undoubtedly had some influence on rooting, but the difference in EC between the control group and the other treatments appeared to be small.

The decision was made prior to medium mixing to omit the use of dolomite lime from the medium. It was believed the natural acidic of the sphagnum peat moss would serve to achieve the proper pH for aluminum availability. Unfortunately the medium was more acidic than expected, and with the addition of aluminum sulfate (an acid-forming substance) the pH

Figure 6: Photo showing drought stress damage following a hot spell.

only dropped further. The method of delivery of the aluminum sulfate may have influenced pH as well. The drench applications sharply increased acidity immediately following treatments, but pH would slowly rise as irrigation water was applied and began to leach some of the aluminum sulfate from the medium. The treatments receiving controlled-release aluminum sulfate however seemed to begin with slightly higher pH values, but as material was released from the prills and started to built up in the growing medium, pH fell steadily until reaching the lowest pH values of the entire experiment.

Many plants may have developed no new roots at all during the experiment as a result of low medium pH and high medium EC. Unfortunately, the lack of root development led to more problems than nutrient uptake. Many plants experienced high levels of heat stress. Hydrangea growers are familiar with plants wilting periodically—not only do hydrangeas have a very large leaf area, they are also believed to lack to ability to close their stomata (citation needed) creating a rapidly progressive situation should the plants become dry. Unfortunately because of poor rooting, the plants in this experiment often underwent extensive wilting despite an extremely wet growing medium, leaf syringing and near-constant light reduction. Several plants became unmarketable and three others died after one particularly hot day (Figure 6).

Not enough attention was paid to the equipment used. For example, the pH/EC meters were rarely calibrated and some difference in readings could be seen when measuring a sample side-by-side with two meters. Care was not taken during several of the measurements to ensure the accuracy of the pH/EC meters. Therefore the results of the pH and EC measurements could be called into question. While it is unlikely that the results were completely wrong, it is likely there was enough variation in measurement accuracy to render some results useless especially given that many measurements were within one significant digit of one another.

When designing the experiment, one measurement per treatment every two weeks was believed to be sufficient in order to keep track of medium chemistry. It became apparent midway through that measuring more often would have been desirable in order to track the fluctuations of aluminum sulfate levels in the treatments receiving drenches versus the steady increase of aluminum sulfate levels in the treatments receiving controlled-release aluminum sulfate. Additionally, after one plant recorded an EC that was quite higher than any other plant in the experiment, it was also realized that more, if not all plants should have been sampled during each measurement to ensure and more accurate reading.

Conclusion

In the fertilizer industry, controlled-release technology has proven itself as a useful tool for growers, especially those producing high-value crops that can benefit from a constant fertility program that is resistant to leaching. Additionally, these controlled-release products can be used in place of expensive fertilizer injection systems. In the relatively small world of Hydrangea production, controlled-release technology has taken some time to make its appearance, most likely due to the industry's small market share. Now, with X-Calibur's introduction of Blue-Knight controlled-release aluminum sulfate, Hydrangea producers can take advantage of this technology by using it in an inherently finicky application. Blue-Knight and its competitors promise to eliminate the pitfalls of water-soluble aluminum sulfate drenches by skirting the issue of leaching entirely.

In this experiment, Blue-Knight showed that it is capable of producing blue hues in hydrangeas on par with traditional treatments. Additionally, due to the slow-acting nature of controlled-release products, plants that received over-applications were relatively unharmed show that Blue-Knight can provide added plant safety during production. Blue-Knight also provided constant product availability for the plants without fluctuations in aluminum levels leading to more consistent inflorescence coloration. But perhaps the product's greatest advantage lies in its ability to greatly reduce labor costs in hydrangea production. The product requires only one application during production instead of one application every two weeks like traditional techniques. Instead of paying a working to dose individual plants twice a month, a single worker can dose an entire crop one time in only an hour or so. When reduced labor costs are combined with lower risk of plant damage, it is clear that Blue-Knight is a superior delivery system for aluminum sulfate. For most growers, the added cost of the product will be out-weighed by its ability to grow a superior crop.

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Appendix A. Table of Raw Data—flower color RBG and RHS color chart values

Treatments			R	G	B	RHS color #
Cultivar:	**Berlin**	1	134	73	117	
		1	124	89	143	
		1	123	63	114	
		avg	127	75	124.6	78C
		2	106	74	137	
		2	124	100	158	
		2	127	65	114	
		avg	119	79. 7	136.3	81C
		3	150	87	134	
		3	177	82	122	
		3	125	91	151	
		avg	150.7	86.7	135.7	74C
		4	158	80	132	
		4	155	75	110	
		4	146	104	154	
		avg	153	86.3	132	74C
		5	133	92	148	
		5	116	76	138	
		5	125	96	154	
		avg	124.7	88	146.7	87C
		6	124	97	152	
		6	126	82	131	
		6	124	101	145	
		avg	124.7	93.3	142.7	82D
		7	138	83	140	
		7	148	105	158	
		7	148	100	140	
		avg	144.7	96	146	78C
		8	121	89	152	
		8	145	86	144	
		8	N/A	N/A	N/A	
		avg	133	87.5	148	82D
		9	178	91	123	
		9	167	67	103	
		9	166	71	105	
		avg	170.3	76.3	110.3	64D
Cultivar:	**Mathilda**	1	97	86	144	
		1	100	95	159	
		1	N/A	N/A	N/A	
		avg	98.5	90.5	151.5	92B
		2	86	76	137	
		2	113	88	143	
		2	114	96	146	
		avg	104.3	86.7	142	85B
		3	101	92	157	
		3	119	100	146	
		3	141	95	142	

		avg	120.3	95.7	148.3	85B
		4	104	90	149	
		4	94	69	134	
		4	121	108	162	
		avg	106.3	89	148.3	92B
		5	83	68	133	
		5	114	89	146	
		5	107	85	149	
		avg	101.3	80.7	142.7	91A
		6	92	78	131	
		6	92	75	129	
		6	105	105	141	
		avg	96.3	86	133.7	88D
		7	105	80	138	
		7	149	89	117	
		7	N/A	N/A	N/A	
		avg	127	84.5	127.5	78C
		8	109	8	142	
		8	133	85	127	
		8	93	76	144	
		avg	111.7	56.3	137.7	75A
		9	160	89	131	
		9	153	98	130	
		9	167	97	125	
		avg	160	94.7	128.7	70C
Cultivar:	**Merritt Sup**	1	139	32	60	
		1	146	41	74	
		1	N/A	N/A	N/A	
		avg	142.5	36.5	67	63B
		2	137	36	66	
		2	148	33	62	
		2	154	40	73	
		avg	146.3	36.3	67	60D
		3	164	43	78	
		3	168	37	71	
		3	N/A	N/A	N/A	
		avg	166	40	74.5	57D
		4	160	49	81	
		4	155	34	67	
		4	155	42	72	
		avg	156.7	41.7	73.3	59D
		5	146	35	68	
		5	158	44	77	
		5	164	60	95	
		avg	156	46.3	80	60D
		6	134	38	76	
		6	143	28	59	
		6	153	63	98	
		avg	143.3	43	77.7	71C
		7	169	47	84	

	7	160	74	101	
	7	144	36	68	
	avg	157.7	52.3	84.3	63B
	8	161	40	75	
	8	157	35	72	
	8	144	30	63	
	avg	154	35	70	60D
	9	160	25	57	
	9	162	33	63	
	9	152	35	64	
	avg	158	31	61.3	57C

Appendix B. Root Growth Table

Root Growth rated 0-3. 0= no visible root growth; 3=roots completely filling the pot

	plant 1	plant 2	plant 3	average
1 ms	2	1	1	1.3
1 ber	1	1	1	1
1 mat	0	0	n/a	0
2 ms	2	1	1	1.3
2 ber	1	0	1	0.7
2 mat	0	1	1	0.7
3 ms	0	0	1	0.3
3 ber	1	1	1	1
3 mat	0	1	0	0.3
4 ms	0	1	2	1
4 ber	0	0	1	0.3
4 mat	0	0	0	0
5 ms	0	1	2	1
5 ber	1	1	1	1
5 mat	1	0	2	1
6 ms	0	0	0	0
6 ber	0	0	0	0
6 mat	0	0	0	0
7 ms	0	0	1	0.3
7 ber	1	1	1	1
7 mat	2	1	n/a	1.5
8 ms	0	1	1	0.7
8 ber	0	0	n/a	0
8 mat	1	0	0	0.3
9 ms	3	1	2	2
9 ber	1	2	2	1.7
9 mat	2	3	1	2

Appendix C. Inflorescence Size Table

headsize (cm)	plant 1	plant 2	plant 3	average
1 ms	10.5	14	n/a	12.25
1 ber	7	9	9	8.33
1 mat	11	12.5	n/a	11.75
2 ms	11	12	12	11.67
2 ber	9	8	11	9.33
2 mat	12	12	11	11.67
3 ms	13	10.5	n/a	11.75
3 ber	8	9.5	8	8.5
3 mat	12	12	12	12
4 ms	13.5	9	13	11.83
4 ber	8.5	7.5	9	8.33
4 mat	10	11	10	10.33
5 ms	12	12.5	14	12.83
5 ber	11	11	10	10.67
5 mat	13	13	12	12.67
6 ms	11	13	10	11.33
6 ber	9.5	10	9.5	9.67
6 mat	11.5	11	9	10.5
7 ms	14	8.5	13	11.83
7 ber	10.5	12	11.5	11.33
7 mat	12	10.5	n/a	11.25
8 ms	12	11.5	13	12.17
8 ber	9	6.5	n/a	7.75
8 mat	10	12	12	11.33
9 ms	13	14	11	12.67
9 ber	9	11	10	10
9 mat	10	5	12.5	9.17